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Title: Impact reduction in football helmets due to application of externally applied foam

Author(s): Vilar-Carrasquillo, Luis D.
Anderson, Brian E.

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Impact Reduction in Football Helmets due to Application of Externally Applied Foam

Luis D. Vilar-Carrasquillo

Summer Student Intern

Mentor: Brian E. Anderson, Ph.D. Acoustics

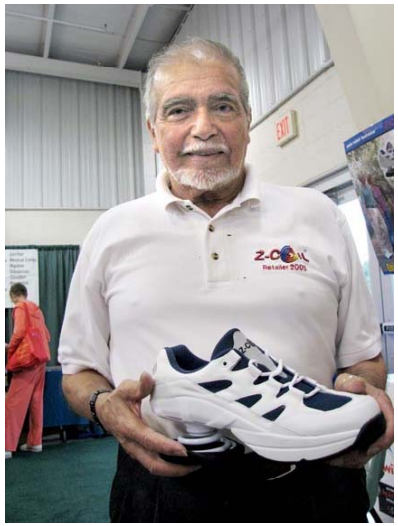
Geophysics Group (EES-17)

Introduction

- Concussions, due to sports hard impacts, are a real concern for athletes, family members, fans of the sport and the public health.
- It is estimated that the number of sport-related concussions in the United States is around 1.6 and 3.8 million per year.
- The measurements utilize a football helmet placed on a mannequin head and consider the response of accelerometers and a high-precision microphone mounted to the mannequin head due to various types of impact tests

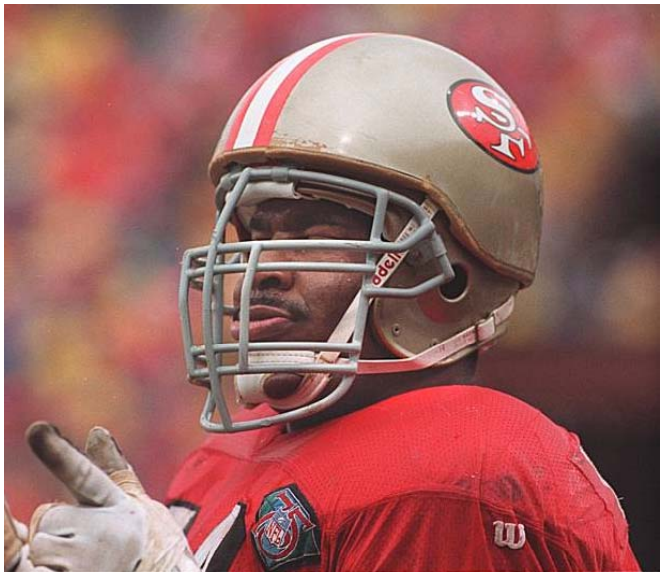
Why this Project?

- This work is funded through the New Mexico Small Business Assistance Program.
- Project between Z-Coil (located in Albuquerque, NM) and the Los Alamos National Laboratory.
- One of the ideas proposed by Z-Coil (aka Z-Tech Footwear) is to use a soft external layer of their internally developed foam bonded onto the outer hard shell of the football helmet.



Other Proposed Solutions

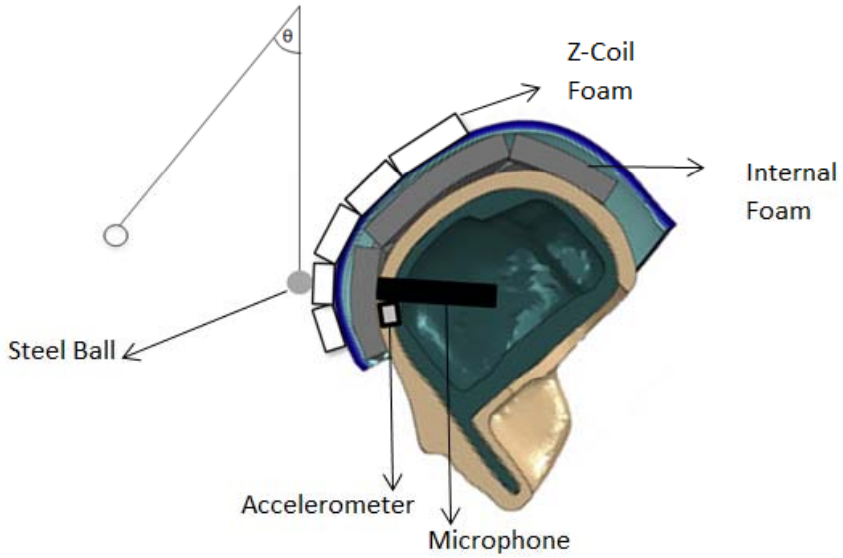
- **ProCap**
- **Gladiator**
- **Bulwark**



Previous Research

- **Manoogian et al., Biomed Sci Instrum, (2006)**
  - Compare helmet shell acceleration to head center gravity acceleration.
  - Peak acceleration for the helmet was ***16.6*** times grater than head cg peak acceleration.
- **Bartsch et. Al, J Neuroseurg, (2011)**
  - Compare the head impact doses and injury risk using 21st century varsity helmets and 20th century leatherheads.
  - The results shows that similar protectiveness profile for leather and modern helmets.
- **Rowson et al., J Neurosurg, (2013)**
  - Biomechanical analysis of classic leather helmets compared with modern helmets
  - Leather helmet had a greater average peak acceleration compared with modern helmets.
- **Nakatsuka et al., American Academy of Pediatrics, (2012)**
  - Test if the addition of external foam layer will reduce the magnitude of the impact
  - Result suggest that the use of an external layer of foam will reduce the injury potential for concussions.

Experimental Setup



- Helmet picture retrieved from:

http://www.sciencedirect.com/science/article/pii/S0734743X12001248

Type of Impact Test

Background Measurements

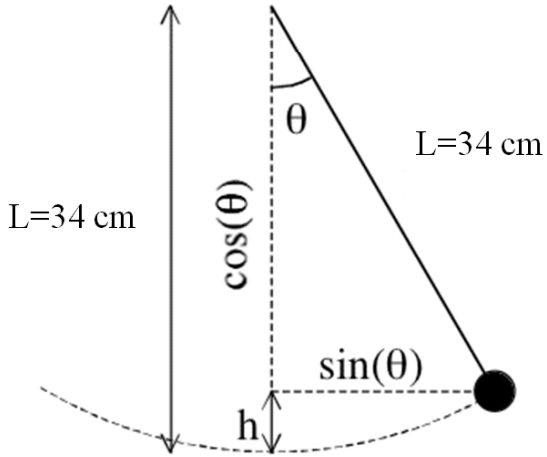
- **Linearity Test**
  - Test of difference w/ and w/o foam vs. steps in angles
- **Repeatability Tests**
  - Steady Setup
    - Ball drop repeatability
  - Moving Setup
    - Setup repeatability
  - Laser Testing
    - Speed of the ball before and after the impact

Potential Final Measurements

- **Force Imparted**
  - Measure Force at the moment of the impact
- **Accelerometer**
  - Measure acceleration of the head in a specific location
- **Pressure**
  - Measure pressure using a high precision microphone

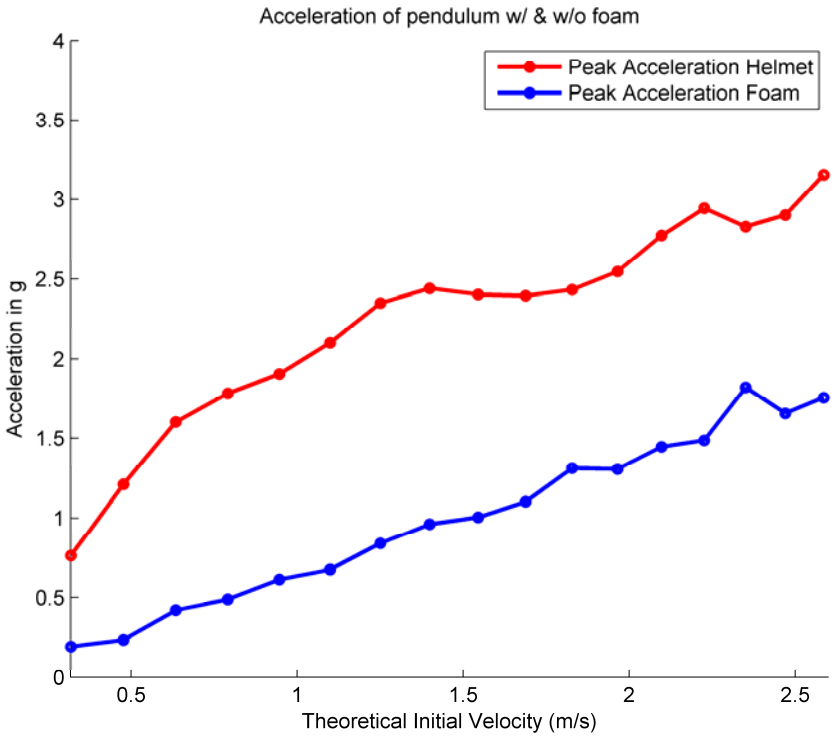
The Physics Behind the Helmet Impact

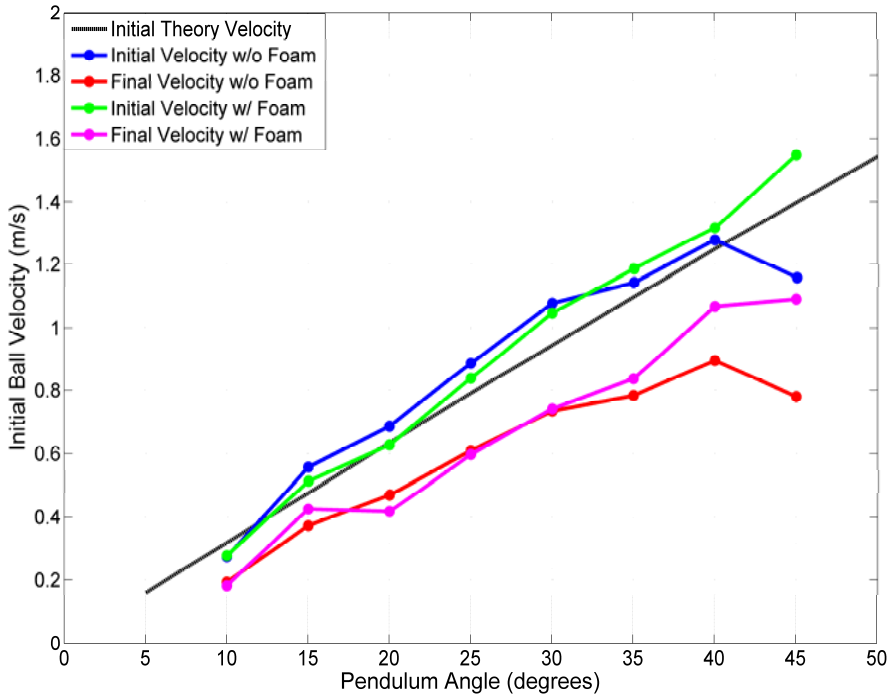
- **Kinetic Energy of the Ball (Before Impact)**
  - $V_l = \sqrt{2gl(l - cos\theta)}$
  - $KE_{l,b} = \frac{1}{2}mV_l^2$
  - $PE_{l,b} = mgh$
- **Conservation of Energy (After Impact)**
  - $KE_{f,b} = KE_{l,b} - KE_{f,s} - PE_{f,s} - Q$
- **Newton's 3rd Law**
  - $F_b = F_s$
- **Force the ball feel at impact**
  - $F = \frac{\Delta p}{\Delta t} = \frac{m_b(V_{f,b} - V_{l,b})}{(t_f - t_l)}$



Linearity Test

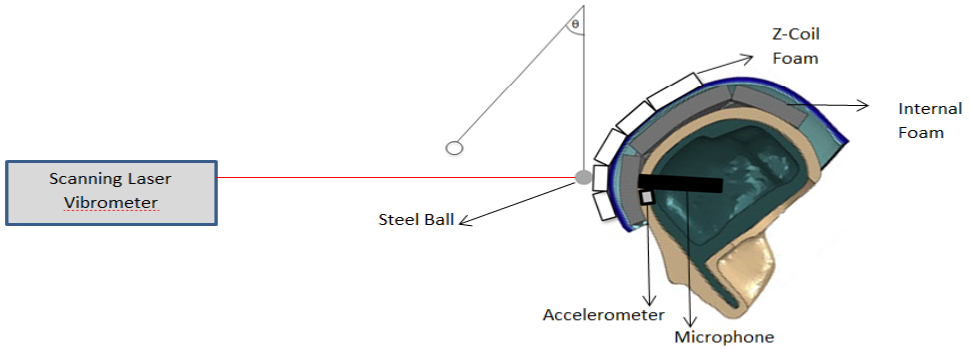
- If the difference in impacts w/ and w/o the foam is linear with impact strength then we can extrapolate our small scale impacts to more realistic ones.

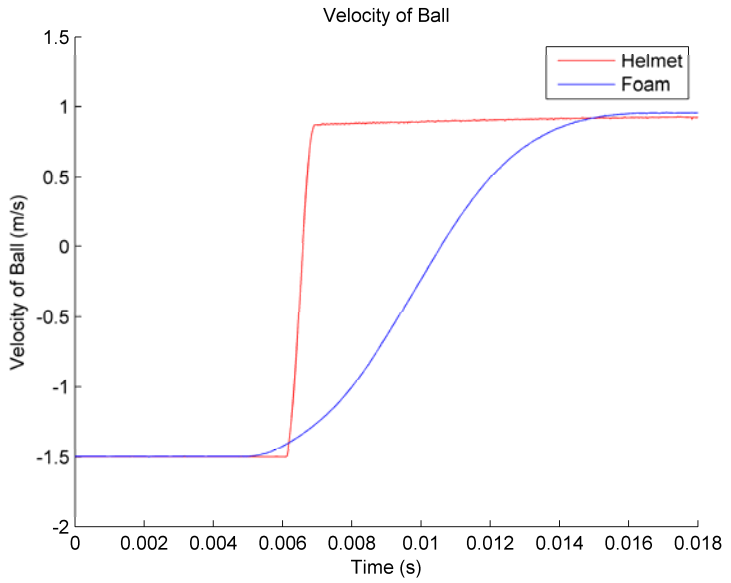




Laser Vibrometer Data (Force Imparted)

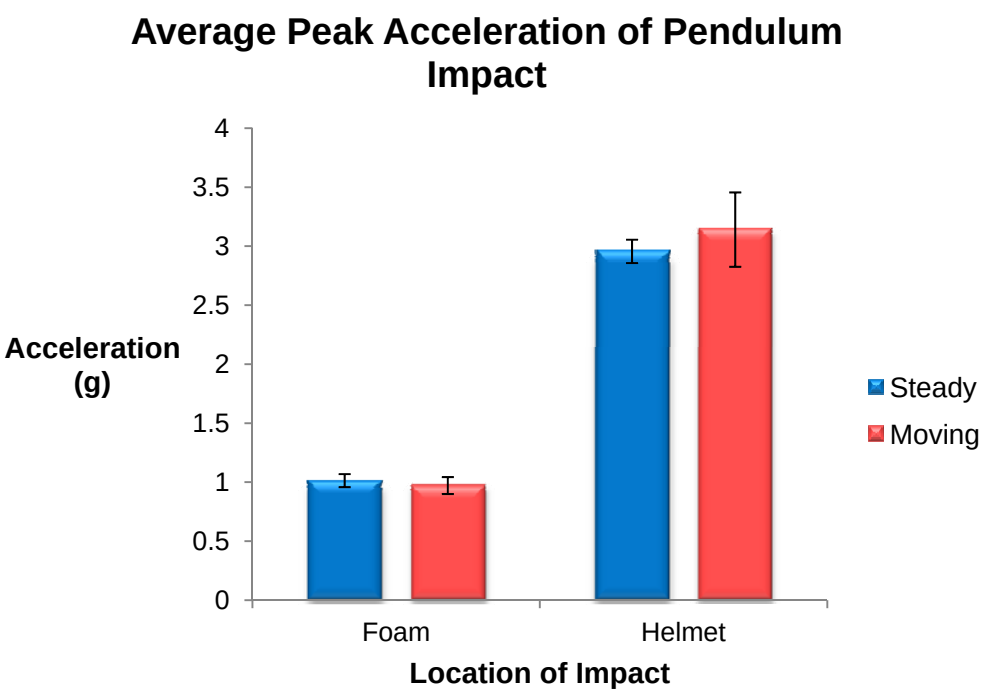
- $F = \frac{\Delta p}{\Delta t}$
- Velocity is almost the same before and after the impact
- Impact Time
  - Foam
    - ≈ 9.9 ms
  - Helmet
    - ≈ 0.87 ms
- $F_H / F_F \approx 13$

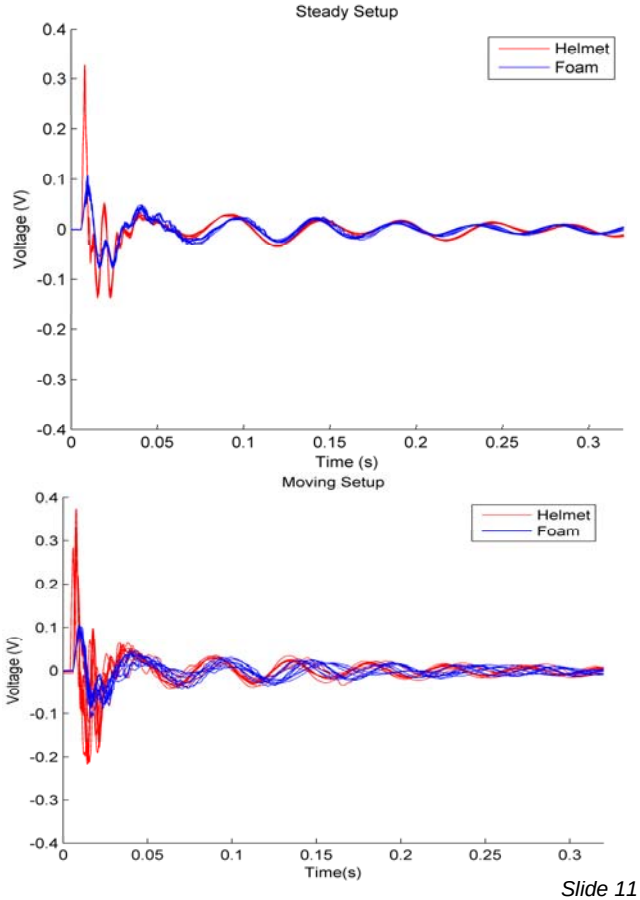




Repeatability Test

- The purpose of this test is to see how repeatable the striking procedure is and how repeatable the results are due to possible setup variations.

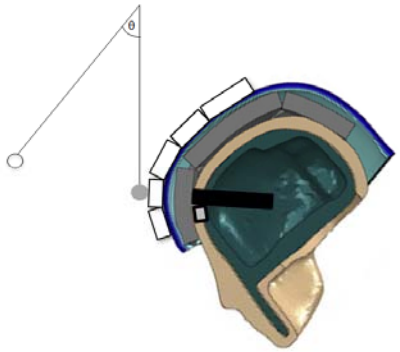


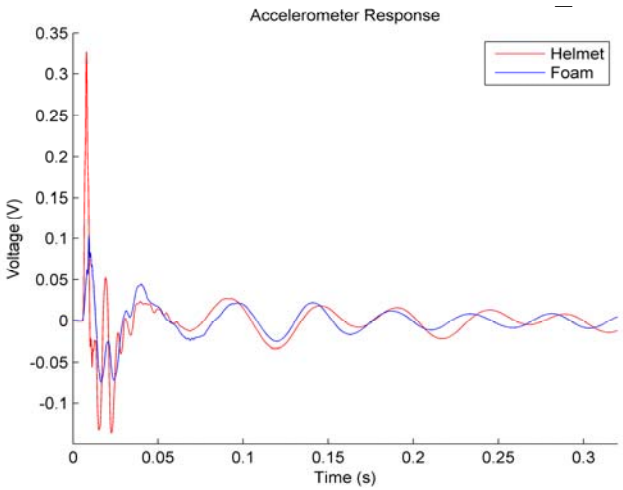


- 10 red signals
- 10 blue signals

Accelerometer Data (Acceleration of the Head)

- **Peak Accelerations Mean**
  - Helmet
    - Steady=3.0208
    - Moving=3.1407
  - Foam
    - Steady=1.0136
    - Moving=0.9719
- **Integral of the Signal Magnitude**
  - $\int_{t_i}^{t_f}(a(t))^2 dt$





- **Ratios of Accelerometer**
  - Steady Test
    - 2.9802
  - Moving Test
    - 3.2316
- **Ratio of Integral of the signal**
  - Steady Test
    - 1.5436
  - Moving Test
    - 1.6966

▪Note: All accelerations are in g's

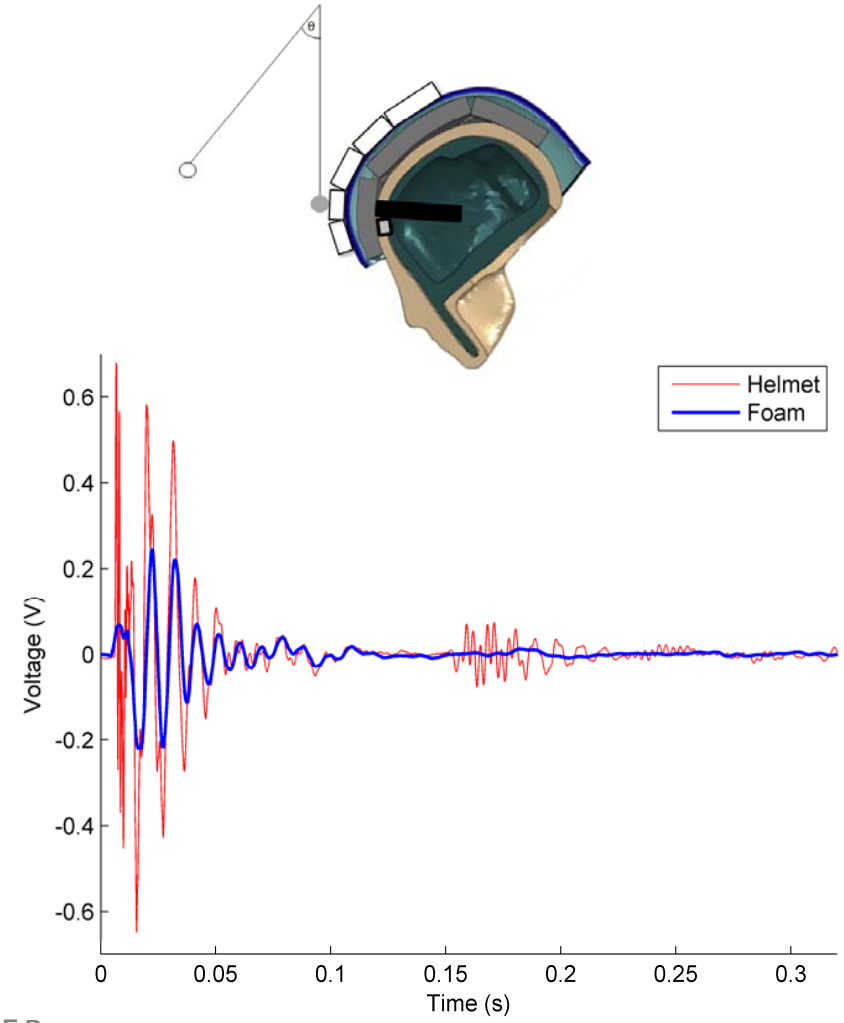
Accelerometer Repeatability Test

	Steady Acceleration Helmet	Moving Acceleration Helmet	Steady Acceleration Foam	Moving Acceleration Foam
Mean	3.0208	3.1407	1.0136	0.9719
Std Dev	0.0992	0.3153	0.055	0.0716
Rel Std Dev (%)	3.28	10.04	5.42	7.37

	Steady Energy Helmet	Moving Energy Helmet	Steady Energy Foam	Moving Energy Foam
Mean	3.7523	4.4547	2.4309	2.6257
Std Dev	0.0958	0.3356	0.1254	0.2849
Rel Std Dev (%)	2.55	7.53	5.16	10.85

Microphone Data (Pressure or Force on Head)

- **Peak Pressure**
  - Helmet=13.62 Pa
  - Foam=4.912 Pa
- **Integral of the Signal Magnitude**
  - $\int_{t_i}^{t_f}(p(t))^2$
- **Ratio of Microphone**
  - 2.7736
- **Ratio of Integral of the Signal Magnitude**
  - 2.0998



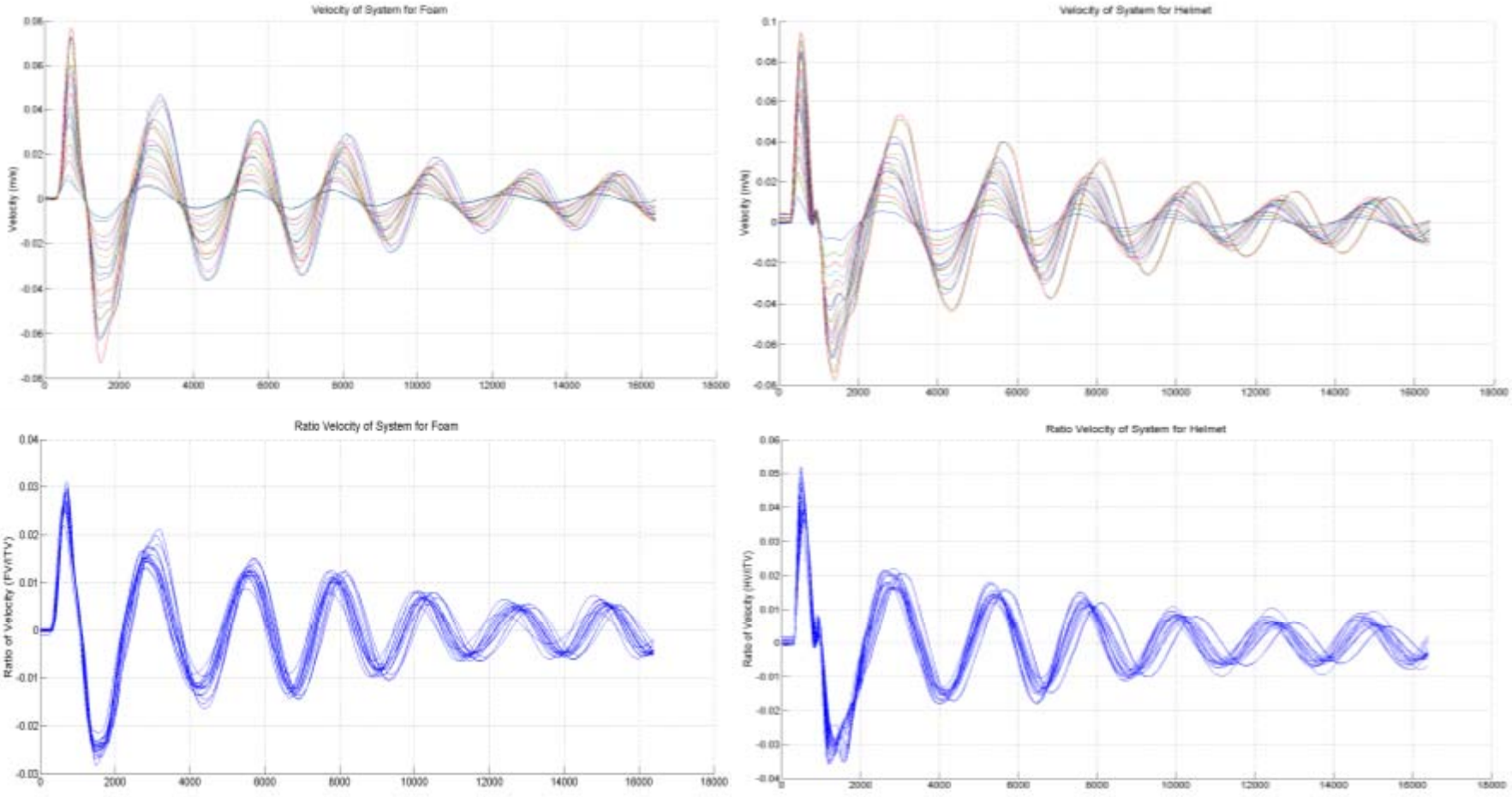
Conclusion

- There is a factor of 13 in change of Force after the ball impact the helmet with and without the foam.
- Ratio of acceleration registered by the accelerometer is around 3.
- Ratio of pressure registered by the microphone is around 3.
- Can be said that the foam will reduce the magnitude of the impact by a factor of 3.
- For report purpose, the factor that will be reported is 3. This is because is the actual difference that the head is receiving.

Future Work

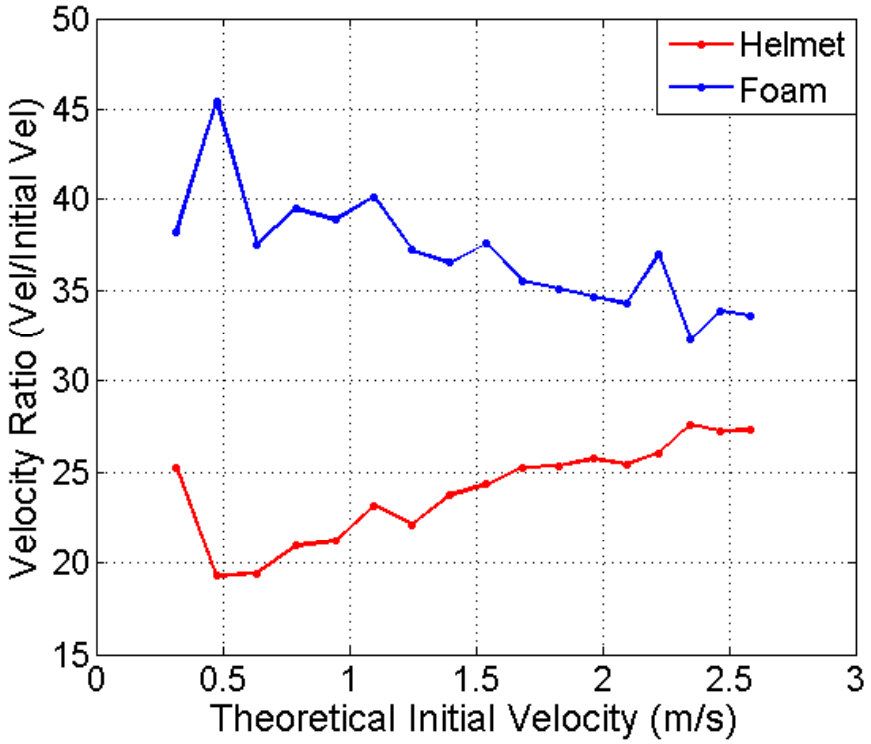
- **Compare different materials**
  - Use compression testing on foams to determine stiffnesses and the absorption rates
- **Use multiple types of testing**
  - Helmet-to-Helmet Pendulum Test
  - Helmet Drop Test
  - Linear Impact
- **Multiple accelerometer locations**
- **Use dummies with flexible neck (mirrors other studies)**
- **Higher impact mechanism**
  - Be able to create concussion-level impacts
  - Be able to create lineal and rotational acceleration impacts

Appendix


Velocity of System for Foam
Velocity (m/s)
Velocity of System for Helmet
Velocity (m/s)
Ratio Velocity of System for Foam
Ratio of Velocity (FV/iTV)
Ratio Velocity of System for Helmet
Ratio of Velocity (HV/iTV)

Appendix

- **The following graph shows the ratio of each peak velocity between the theoretical initial velocity**



Gracias por su atención (Thanks for your attention)

Questions?